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# MEASUREMENT OF ELECTRON DENSITIES IN THE MIDDLE ATMOSPHERE USING ROCKET BORNE BLUNT PROBES

OCTOBER 1979





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US Army Electronics Research and Development Command
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Detailed consideration has been given to the determination of electron number density from conductivity data gathered by rocket borne blunt probes in the middle atmosphere. A definition of the difficulty of electron density determination is presented. The procedures of determination of ion densities in the middle atmosphere are reviewed and critically evaluated. The specific aspects of particle collection by a supersonic probe are evaluated and compared to those of a subsonic probe; it is indicated that compression (x10) regions will → next page

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form in front of supersonic probes at altitudes up to 100 km, and that electron attachment rates could significantly alter electron and negative ion concentrations. A summary of the analysis of negative conductivity data to indicate electron density is presented. Data from four days, January 31, 1972, and December 5, 1972 (WI), and October 2, 1975, and September 29, 1977 (WSMR), are reduced and electron density profiles presented; these are compared with the indication of electron density from other diagnostics. In the region of overlap of data, there is general agreement in the electron density predictions; the indication of electron density at altitudes below 70 km are new, but the theory for this region is felt to be most accurate.

## CONTENTS

## Introduction

The chemistry of the stratosphere and middle atmosphere, or D-region ionosphere, which lies between 30 and 100 km continues to be of considerable interest[1]. In particular, a knowledge of the ionization of this region is important in determining electromagnetic transmission characteristics[2,3]. Measurements of conductivities and mobilities of positively and negatively charged particles are being carried out with rocket and balloon borne probes[4,5]; however, there is a need for precise analytical connection of these measured properties of the medium to local particle concentrations or number densities. This effort will address questions relating to the understanding of particle collecting mechanisms during sampling and the accuracy of methods of determining concentrations from related data. In particular, the determination of electron densities from negative conductivities measured by subsonic blunt probes will be of primary interest.

Regarding the structure of the D-region in general, a survey paper was published by Thomas[6] in 1974 which concentrated on discussions of ionization processes and ion densities. An interesting paper which adds a new ingredient to this problem, proposes the existence and explores the effects of ice particulates in the structure of the mesosphere between 65 and 90 km, has also been presented[7]; the compatible interpretation of positive and negative conductivity measurements is an integral part of the evidence in that work. A study exploring the relationship of conductivity measurements to radio wave absorption has also been presented[8].

Regarding the specific problem of electron density determination and behavior, two articles by workers at Illinois tend to identify the present state of understanding[9,10]. The paper by Sechrist[9] reviews ground-based and rocket techniques that are used to determine electron density profiles. Radio propagation techniques as well as Langmuir-type probes are noted as being used on rockets. Data is presented for some typical days. It should be noted that this data is taken with supersonic rocket velocities. The paper by Mechtly presents considerable data and has a detailed discussion of rocket techniques. The Langmuir-type probe is used to record (electron) current collected with a fixed, positive bias on the collector; while there is no indicated theory for relating this current to electron density, for each shot the electron current is pegged to a current density at an appropriate altitude ($\sim$90 km) and the inference of electron densities at other altitudes is made by relative value. In general, the diagnostics that are alternative to rocket borne particle collectors are not functional below 70 km. With some degree of overlap (several tens of kilometers) in altitude of data, it is precisely these altitudes below 70 km that are of primary interest here. Blunt probes have typically shown negative conductivities with values greater than positive conductivities at altitudes above 40 km, and the correct interpretation of this data is intended. The implication[9,10] of negligible (i.e. $N_e < 50$ cm$^{-3}$) electron density at altitudes below 70 km based on the inference of relative current, without theoretical justification, seems premature. It is also useful to note here that other evidence from a Langmuir-type electron collector has been presented[11]; this data has different implications. With the same type of device as that flown by Illinois, significant electron saturation currents were evident to low altitudes ($\sim$30 km). Indeed, until each of these particular probing devices is properly analyzed in detail, the electron density indications are questionable. Before leaving this topic and discussing specific aspects of probe theory, it should be noted that the work by Rowe[12] not only provides a theoretical model for the D-region structure based on wave interaction techniques, but also provides a comprehensive summary of all of the important measurement results of electron density from earlier workers.

## The Blunt Probe-Ion Collection

The intent of the discussion here is not to present or define any theory or formulation for ion collection, but rather to reiterate the accuracy and constraints on previously reported work. It is useful to identify and state the basis for confidence in the method of determining ion conductivity from negatively based collector electrode data.

The first work specifically applicable to blunt probe ion collection in the lower ionosphere was presented by Hoult[13], which followed and specialized the general analysis of Lam[14] for flowing, weakly ionized gases. Hoult's calculation was approximate in approach, as he presumed an unperturbed ion density except in a thin diffusion layer of thickness $L/\phi_w$ at the collector surface where $\phi_w = eV_w/kT$; this analysis neglects any convection effects. The influence of flow on ion collection was correctly included in an analysis of this regime by Sonin[15], whose formula for the relationship of ion conductivity to current-voltage characteristics reduced to Hoult's, but only for a limiting condition of strong applied field. For blunt probe operation, it has been shown[16] that this limiting condition is met under D-region probe conditions[17]. The work reported by Lai[16] specifically confirms the accuracy of ion conductivity determinations from negatively biased collector electrode blunt probe data as carried out by Hale[17].

In brief, it is established that ion collection is not perturbed by flow or electric field extent, and collection occurs in a thin diffusion layer over the surface, as

$$dI = eN\mu EdA$$

where dI is the current collected by an element of area dA, E is the surface electric field, $\mu$ is the ion mobility, and N is the number density of charged particles collected. With the blunt probe, a linearly swept potential ($\pm$ 10 volts) is applied between probe and return electrodes. The dI/dV is related to conductivities ($\sigma+$, $\sigma-$) with a linear dI/dV, as

$$\sigma = \frac{R}{2r^2} \left| \frac{dI}{dV} \right|$$

where R is the outer radius of the guard electrode and r is the radius of the collector electrode. The ion density is then expressed as

$$N_+ = \frac{\sigma+}{eu_o^+} \frac{T_o}{T} \frac{p}{p_o}$$

where $u_o^+$ is the reduced mobility at conditions $T_o$, $p_o$.

More recently, there have been several comprehensive evaluations of electric probe theories presented in the literature. These critical reviews serve to place most calculation schemes in perspective, to restate their significance, and to clarify their correctness. Chung, Talbot, and Touryan provide two papers[18,19] that discuss the details of both collisionless and collisional probe theories. Smy[20] concentrates on the probes used in high pressure plasmas, but also specifically does discuss general experimental data as well as specific ionosphere data. In both these works there is an implicit statement of the correctness of the theory of ion collection presented by Hoult and Sonin for the regime in which it is applicable. In Smy's work, there is an explicit discussion of the accuracy of Hoult's result for ions based on a recent work[21]; it is concluded to be accurate for a limiting condition ($\frac{eV}{kTe} > 10$). For ionosphere plasmas with Te = 0 (300°K) there, the theory is applicable for V > .3 volt.

It is appropriate and important to restate here that while these probe techniques indicate ion conductivity, there still are questions regarding the relationship of conductivity to particle concentrations. Specifically, with regard to ion concentrations, the preeminent question relates to the existence of ion clusters[7,22]. Should such clusters be perturbed (broken-up) by interactions involved in the particle collection event, the accuracy of the standard evaluation of ion density could be affected.

It will be noted here that, while there is confidence in the use of probes to determine ion conductivity and theory to predict concentration when there are no composition changes because of the probing, there is not confidence yet in electron collection procedures and data analysis. The primary reason for this present state of affairs is the nonlinear behavior of electron drift velocity, under variable E/p conditions that exist in data collection. The results of a study to clarify electron collection processes and present a new procedure for determination of electron densities will be reviewed below.

## Probe Flows-Subsonic vs. Supersonic

The process of gathering composition related data to indicate structure and changes of structure of the middle atmosphere is being continued by workers using subsonic[4] and supersonic[10] rocket borne probes. The speeds of Nike-Apache rockets have been characterized as hypersonic[23], but specific data on speeds vs. altitude on these rockets have not been available. It is not the intent in this section to present any new theory for flow or chemistry effects in front of supersonic vehicles, but rather to review and emphasize the clearly stated results of work presented earlier.

An early paper by Hoult[24] examined the effect on composition of shock waves generated by a M = 2, 5° wedge. He took a simple model of the density changes with altitude, reaction rates as they were then known, and concluded that there indeed were significant effects due to shocks. He found electron attachment rates to be fast enough to alter electron and negative ion concentration below 70 km, with 50 percent errors at 50 km. It should be noted that a 5° half-angle wedge generates a shock that is weaker than one would expect, and also, that electron attachment rates are even now in question, probably being significantly higher than presently accepted values. Even these calculations should be repeated for reasonable bodies at current attachment rates. Impurity effects could considerably exaggerate these effects. In a later work[15], Sonin reiterated these same concerns and added the additional possibility of positive ion density alteration by shock induced chemical effect on water vapor. To clearly state the implication here, increased densities generated by compressions would reduce the electron density and increase the negative ion density by enhanced attachment.

One experiment has been conducted to examine the subsonic-supersonic collection question, but it was carried out at night so that the electron attachment question could not be evaluated[25]. A spherical tip collected on a supersonic upleg, and a blunt probe collected on a subsonic downleg. The published results show that the ion sampling was badly disturbed by the shock; a reduction error in this data was noted, but it does not change the general conclusion. With corrected data, negative conductivities were the same on both legs, but positive conductivities were: $\sigma+(\text{sub}) < \sigma+(\text{sup})$. Because of the poorly known $H_2O$ concentrations, it is difficult to tell if this could be related to the $\sigma$ change. It would seem reasonable to consider further analyses and possible rocket flights to answer these questions.

A more general question should be considered: Where will shock waves (or compression regions) form--What altitudes and about what shapes? Early work[24] expressed the idea that the effect of shocks is negligible above 70 km; this was based on the expectancy of shock formation up to about 80 km (where mean free path $\sim$ 0.1 body diam) with the lower density at higher altitudes suppressing any density change effects. However, one must be careful in the identification of proper flow parameters and relevant experimental work. Specifically, a later effort[26] dealing with experimental studies of shock formation at about M = 7.0 in $N_2$ also reviewed experimental evidence down to M = 3.0, and related theoretical work. It is specifically reported that shock waves with discontinuous changes that conform to normal understanding occur with Knudsen numbers (mean free path/body radius) up to 1.0, ie $\lambda_{nn} \precsim R_B$. Based on that criterion, density enhancements appropriate to shock jumps should occur up to 100 km on a 10 cm diam. body.

Another later work[27] has raised serious questions about ignoring the effects of shocks/density enhancement with supersonic probes. Specifically, the work of Long and Vogenitz[27] presented the results of a unique set of calculations to determine the effect of body interactions on sampled ions. They did indicate significant effects of the body at all altitudes. However, more interesting here is the indication of density increases at supersonic speeds at high altitudes. In the case with minimal effect, with $M = 3.4$ on a shape with 11.25° cone half angle, at 100 km, the density at the stagnation point (cone apex) is 1.5 times (50 percent increase) ambient density. The temperature was increased by a factor of 2.5 times ambient. The Knudsen number here is 1.4, based on body radius. At 100 km with a blunt shape, the density was seen to increase by a factor of 12.0 and temperature by a factor of 4.0! More recently[36], a study of transition flow about axisymmetric right-circular cylinders was presented; the results show strong density increases ($\rho/\rho_\infty \sim 10$) up to Knudsen number of 10. Clearly, one must be concerned about the proper inclusion of such effects in any data reduction scheme!

## Blunt Probe-Electron Collection Theory

A detailed description of the analysis of electron collection and the determination of electron density from conductivity data will not be presented here. That information will be contained in a report[28] in preparation, which will clarify and complete an initial exploratory study that had been reported[29]. Similarly, work involving laboratory verification of probe theories is underway[30] and will not be described here; this work will clarify and complete an initial exploratory study[31]. Rather, the general approach followed in the analysis will be outlined and resulting formulas presented.

In the analysis of ion collection by a moving probe presented by Hoult[13], he specialized the equation of ion flux presented by Lam[14] to be the sum of convection, mobility, and diffusion terms as

$$(R\, d\, \vec{q} - \phi_w \nabla\phi) \cdot \nabla n^+ - \nabla^2 n^+ = 0$$

It is reasoned that as collection is presumed to occur close to the surface, convection is neglected, because any boundary layer will result in low velocities there, and collection is presumed to be dominated by mobility and diffusion as

$$-(\phi_w \nabla\phi) \cdot \nabla n^+ - \nabla^2 n^+ = 0 \ ,$$

with a natural thickness of this region of $1/\phi_w = L/(eV/kT)$, which is quite small. The density variation that results is

$$n^+ = n_\infty^+ \{1 - e^{-\frac{\partial\phi}{\partial z} z}\} \qquad \text{where } \phi = eV/kT \ , \quad V = \text{potential}$$

$$z = \frac{z'(\text{physical distance})}{L(\text{body size})}$$

The ion collection to an element of area dS is physically stated as

$$dI = eD\left(\frac{\partial n^+}{\partial z}\right)_{wall} dS$$

which becomes $dI = e\, n^+ \mu\, E_w dS$, as above.

In the collection of electrons, the scalings have been reexamined and are drastically different from those for ion collection, but a more basic physical understanding is that the electron drift velocities in the applied E field are much higher than any flow or diffusion velocity. The collection of the electrons by applied fields (mobility) dominates the problem. The equation for particle conservation in electron collection by a moving probe is written

$$\beta\, Rd\, q \cdot \nabla ne - \nabla ne \cdot \nabla\phi - \nabla^2 ne = 0$$

where $\beta = \frac{Di}{De} = \left(\frac{me}{mi}\right)^{1/2}$, $Rd = \frac{UL}{Di}$ and $\beta << 1$

Analysis[29] indicates a surface diffusion-mobility layer of thickness $\phi_w^{-1}$, adjacent to a mobility dominant layer of thickness, L. However, on consideration of electron neutral mean free paths, $\lambda en$, it is found that $\lambda en > \phi_w^{-1}$ in D-region ionosphere plasmas, thus invalidating the diffusion layer concept. Obviously, particles are collected near the surface in a layer governed by kinetic theory.

As electron collection is dominated by field induced drift velocities, and these velocities are quite high ($10^5 - 10^6$ cm/sec) it is presumed that electrons will follow lines of electric field to the probe surface. Further, as mobility dominates the motion of electrons, experimental curves of drift velocity vs. E/p must be used. This data for electron drift in nitrogen is presented in McDaniel[32] and is utilized in the results presented below. With a mapping of E field for the collector-guardring geometry, the electron flux through these field lines was computed, and the electron flux was found to "saturate," i.e., reach a large, relatively constant value at a large distance from the collector. This value of flux is much larger than that which could be induced by motion of the collector (flow), and so the collection of electrons for a moving or static blunt probe is the same. The distance from the collector at which the flux will saturate can be expressed as (in air)

$$\gamma = 5\ a\left(\frac{Ew}{p}\right)^{1/2} \quad \text{and,} \quad Ew = \frac{2Vw}{\pi a}$$

so

$$\gamma = a^{1/2} \left(\frac{50\ Vw}{\pi\ p}\right)^{1/2}$$

where a is the radius of the guard ring (cm), Vw is the voltage applied to the collector (volts), p is the gas pressure (mm Hg or Torr).

For low altitudes (high pressures), the $\lambda en$ is small, and the particles that are collected can be presumed to be those gathered at the saturation radius, $\gamma$. The electron velocity at the saturation radius is taken to be $v_D = 3 \times 10^5$ cm/sec. The electron density can be shown to be the undisturbed electron density, $Ne_\infty$, and the area of the flux tube at the saturation radius can be shown by field flux conservation to be

$$A = \pi\ r_{col}^2 \frac{\gamma^2}{a^2}$$

where $r_{col}$ is the radius of the collector disk (as opposed to ground-ring radius, a). The electron current collected by a blunt probe at low altitude ($\lambda en << L$)

$$Ie = e\, v_D\, A\, ne_\infty$$

or

$$Ie\ (\text{amp}) = 50\, e\, \frac{r_{col}^2}{pa}\, v_D\, ne_\infty\, V_w$$

where e is the electronic charge. One can directly find $ne_\infty$ from Ie data at $V_w$, or, taking a derivative

$$\frac{d\ Ie}{d\ V_w} = 50\, e\, \frac{r_{col}^2}{pa}\, v_D\, ne_\infty$$

but, as is normally done[17],

$$\sigma = \frac{a}{2r_{col}^2}\left(\frac{d\ Ie}{d\ V_w}\right)$$

so

$$ne_\infty = \frac{p\ \sigma-}{25\ e\ v_D} \qquad \text{for } \lambda \le a/2$$

$$= .833 \times 10^{12}\ p\ \sigma-$$

For higher altitudes where the longer electron-neutral mean free paths could alter the collection process, the analysis must be adjusted to account for this. One method, which will not be spelled out in detail here, involves the identification that $\frac{d\ Ie}{d\ V_w} \sim \frac{d\ A}{d\ V_w}$ ; at higher altitude where $\frac{dA}{dV}$ would increase significantly, and there would be a loss of electrons through random thermal motion, the $\frac{dA}{dV_w}$ would be held constant. Analytical arguments can be made for pegging this altitude location at a point where the radius (from axis) of the collection area at $\gamma$ will be equal to $\lambda en$. However, this is an approximate attack, and its results will not be given here. Rather, the results of an analysis which is physically and analytically satisfactory will be given. The basic premise here is that, as before, electrons at $\gamma$ will be a part of the electron flux to the surface. However, the electron in the electric field flux tube intersecting the outer guard-ring will be gathered; this is larger than that for the collector radius. However, as these particles are drawn toward the surface, the density of particles that will be collected at $\lambda$ from the surface is different from $ne_\infty$ and particles are gathered in a kinetic fashion. Specifically, for $\lambda \sim a$, a flux conservation would be

$$ne_\infty A_\Lambda v_D = ne\lambda[\pi a^2 + 2\pi a \lambda en] \frac{\overline{Ce}}{4}$$

where $\overline{Ce}$ is the random thermal velocity of the electrons, and the current collected is

$$Ie = e \frac{ne\lambda \overline{Ce}}{4} (\pi r_{col}^2)$$

so

$$ne_\infty = [1 + 2 \frac{\lambda}{a}]K(.4) \times 10^{12} \text{ p } \sigma- \qquad \text{for } \lambda en \sim a$$

where K = 2.14 for Loki Dart and K = 1.54 for Super Arcas.
Similarly, for $\lambda > a$, the collection of random flux to the surface would be through a hemispherical area, as

$$ne_\infty A_\Lambda v_D = ne_\lambda [2\pi \lambda_{en}^2] \frac{\overline{Ce}}{4}$$

and, as above

$$ne_\infty = (\frac{\lambda en}{a})^2 K(.8) \times 10^{12} \text{ p } \sigma- \qquad \text{for } \lambda > a$$

In the above formulations, there are several facts worth noting. First, it is evident that $ne_\infty$ can be derived from data involving Ie at $V_w$ and slope of the Ie, $V_w$ characteristic $(\frac{d\ Ie}{d\ V_w})$. This point is interesting, as the reduction of data by both should be consistent; there is the fact that local electric fields could be present[33], and so perturb the collection process in the constant bias case.

For example, a probe biased at a fixed voltage to collect electron saturation current, presuming that there is a direct dependence on $V_w$ in this long Debye length regime, would exhibit a changing electron current with altitude that could be related to changing fields in the ionosphere rather than density changes. A probe sensing $(\frac{dI}{dV})$ at a point would not be influenced by such a changing field structure. Second, there had been an interesting observation regarding values of $\sigma$ reduced from blunt probes of different size. Specifically, larger diameter (a) blunt probes had indicated larger values of $\sigma-$ than smaller diameter probes. Considering the formulation for $ne_\infty$ for $\lambda \sim a$ which covers most altitudes of interest, one can see $ne \sim (1 + \frac{2\lambda}{a})^{\sigma-}$. Accordingly, if, on the average one expects the same order of ne at an altitude, the $\frac{\lambda}{a}$ term would be smaller for large a, thus resulting in larger $\sigma-$, to be consistent.

In terms of mean free path effects in general, there is some concern with the technique if indicating electron densities at low altitude by extrapolation of a "calibration" of a collected electron saturation current at higher altitude[9,10]. Specifically, at high altitudes, 70-100 km, there is a considerable collisionless character to the collection of electrons. At lower altitudes (40-70) the mean free path is much smaller, and indeed this region must be considered more appropriately collisional ($\lambda en \ll L$) as opposed to collisionless ($\lambda en > L$) at higher altitudes. There is already considerable evidence[18,34,35] that, in general, the effect of collisions serves to reduce currents collected by a probe. Accordingly, a probe with constant bias that is calibrated at 90 km would be expected to have an overlay of reduction in current collected because of collisional effects in addition to any reduction due to density decrease. It would seem that such indications of density below 70 km should be evaluated for corrections that would increase the predicted ne.

## Blunt Probe-Data Reduction and Comparison With Other Diagnostics

The analysis of the electron collection processes outlined above resulted in formulas for electron density from I-V data or (dI/dV) data. In order to examine the relevance of these formulas, and this analysis, it is useful to compare the predictions of number density with those of other diagnostics. Fortunately, two separate and independent sets of data have been taken with blunt probes on days and at times that allow such comparison. First, during the Winter Anomaly campaign at Wallops Island, on two days (January 31, 1972 and December 5, 1972) Hale and Mitchell[8] had launched a Super Arcas blunt probe shortly after a probe package had been launched by researchers from the University of Illinois[9,10]. The latter probe was supersonic and fitted with a nose-tip Langmuir probe, as well as electronics appropriate for Faraday rotation and differential absorption measurements. Comparisons were also made with partial reflection data in some published cases. Second, during the STRACOM balloon series at White Sands Missile Range, blunt probes were launched on Loki-Dart rockets by Mitchell and Olsen on October 2, 1975 and September 29, 1977; on those days partial reflection data were also recorded. Reduction of data taken during each of these events will be presented and discussed. It is to be noted that there will not be a comprehensive evaluation of general techniques, specific equipment limitations, or detailed calculation procedures presented here. However, these comparisons are intended to serve as a basis for a relative consideration of all diagnostics.

The electron density data taken during the Wallops Island tests in 1972 have been published by the Illinois group[9,10], and the techniques have been critically reviewed in their articles. It is these published results that will be utilized in the presentation that follows. While conductivity data ($\sigma+$ and $\sigma-$) have been published by Hale, there has been no recent attempt to indicate electron densities, as there was no confidence in the application of ion collection theory to predict electron densities. In order to provide some relevant background information on those days, the summary of $\sigma+, \sigma-$ is presented in Fig. 1. Data taken on January 31, 1972 and December 5, 1972 were reduced; number densities are presented in Figs. 2 and 3. Several related number density predictions published by Mechtly[10] and Sechrist[9] are also reproduced here. The electron density points (ref. 10, Mechtly) for January 31, 1972 are primarily from Faraday rotation measurements; the partial reflection data was taken at Wallops Island at 12:12 local time. Without attempting detailed description or discussion of these predictions from blunt probe data, the $\lambda$ limit analysis is the same order of magnitude, with similar shape and is no worse than a factor of 5 different from Faraday rotation. This is a generally average day during the Winter Anomaly (Fig. 1) and the predictions are in reasonable agreement. The predicted electron number densities for December 5, 1972 are shown in Fig. 3. The electron density points from Mechtly[10] are primarily differential absorption. Clearly there is very good agreement here of the blunt probe predictions with all other diagnostics. There was no published partial reflection data. From Fig. 1, it can be seen that this was a somewhat "disturbed" day.

The second set of data was taken on two days during the fall, two years apart. The blunt probe data was reduced by the procedures noted above, and it is presented with predictions of ne provided by Olsen and Mott; it should be noted that the reduction of partial reflection data is undergoing evaluation and improvement, so this ne profile should be considered preliminary.

For October 2, 1975 with the smaller (than ARCAS) Loki-Dart probe, again there is reasonable agreement in magnitude and general shape of ne predicted by blunt probes and partial reflection. The partial reflection sequence of profiles is erratic and there is none at the time of probe launch; indeed, one would expect ne at 1615 from partial reflection to be lower than that indicated at 1531. The data taken on September 29, 1977 was reduced and ne predictions presented in Fig. 5. Again, the partial reflection data must be considered preliminary. The agreement in magnitude and slope, however, is quite good.

It should be noted that in the indications of number density by blunt probes, the method used to derive ne was that working with $(dI/dV)_- \sim \sigma_-$. A method using I-V data is also possible, but this reduction is not yet completed. These results will be presented and compared with other predictions in the basic report of probe theory[28], which is presently being prepared.

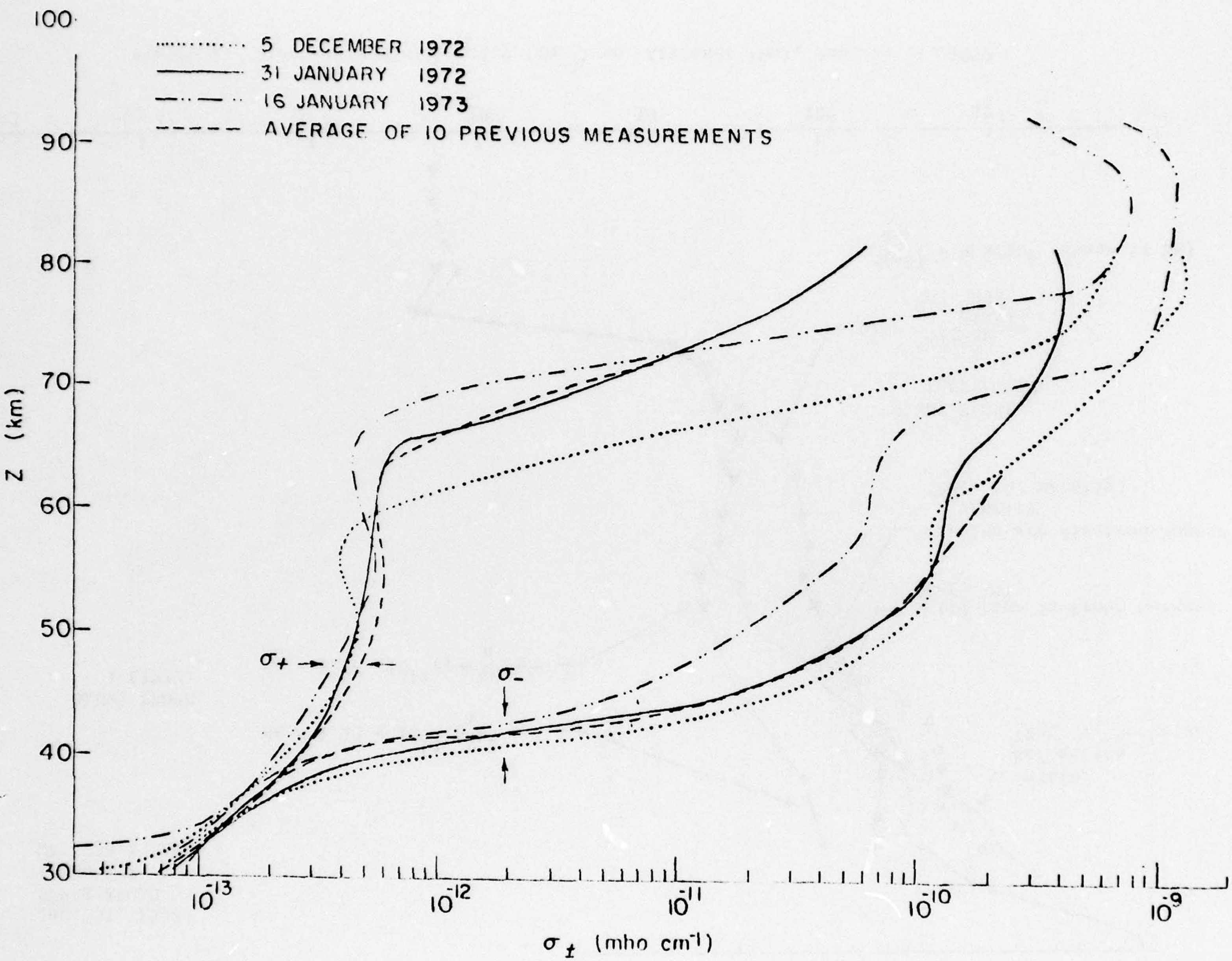


Figure 1. Summary of positive and negative conductivities.

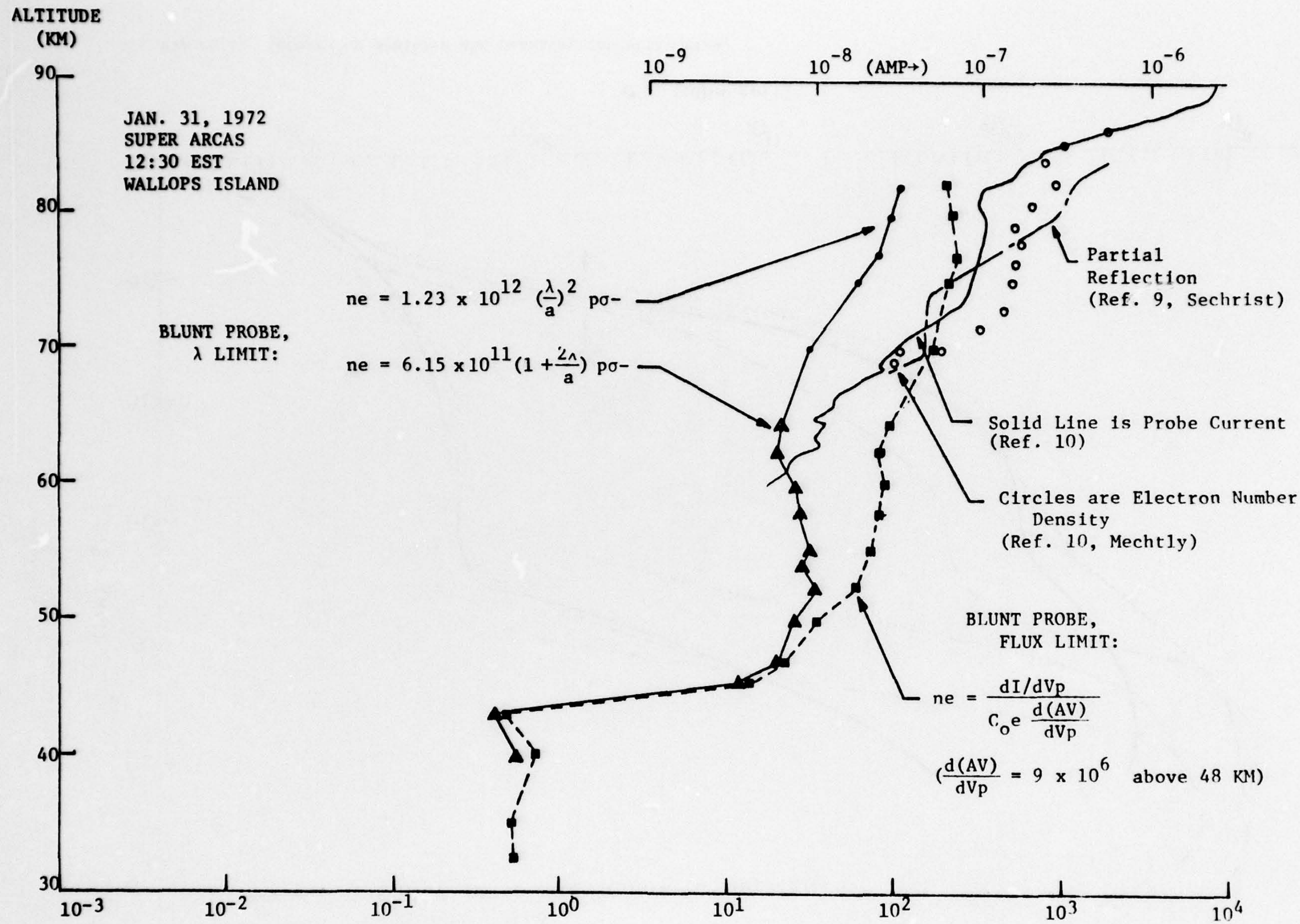


Figure 2. Electron Number Density ($cm^{-3}$) vs. Altitude (km), January 31, 1972

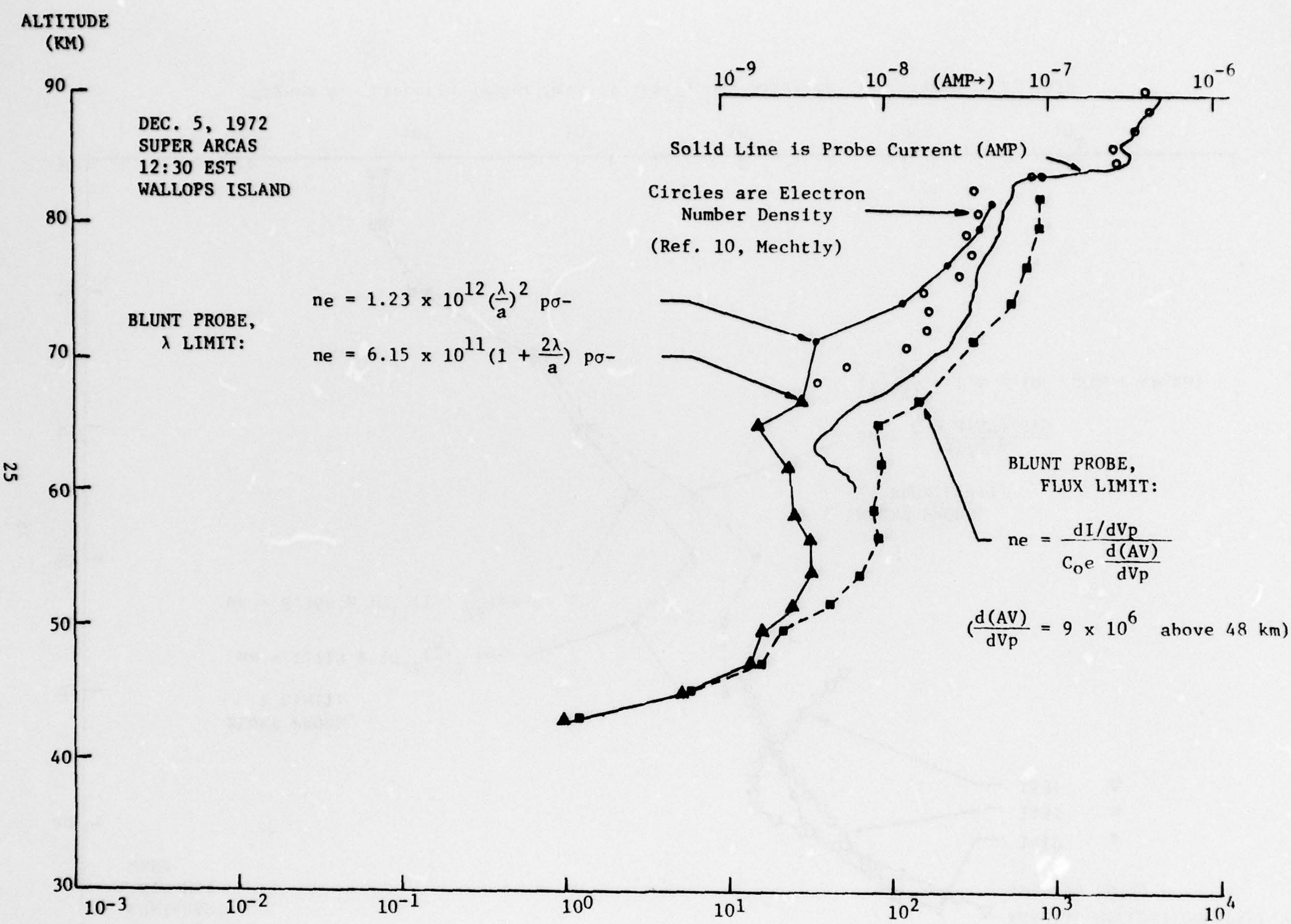


Figure 3. Electron Number Density (cm-3) vs. Altitude (km), December 5, 1972

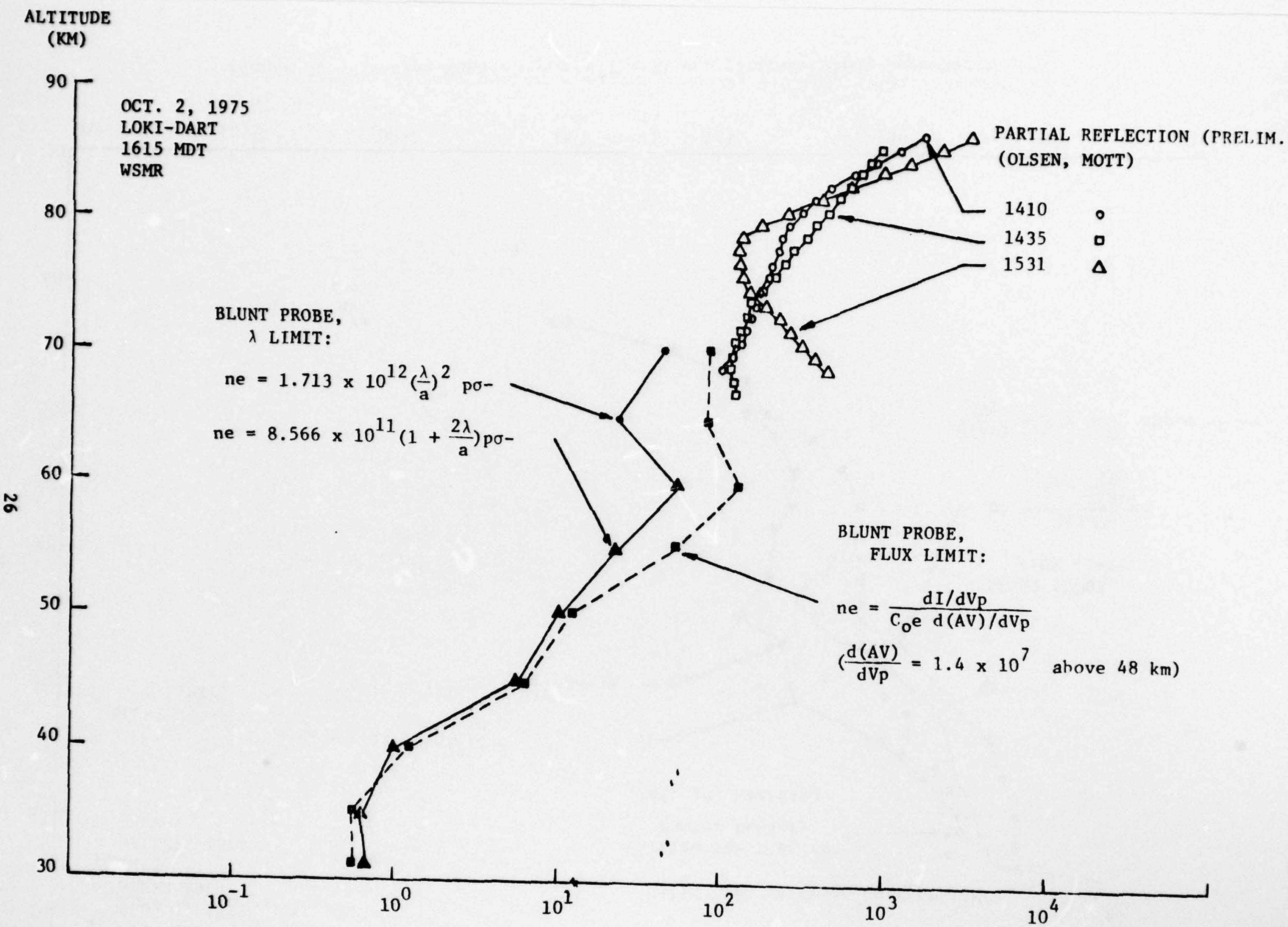


Figure 4. Electron Number Density ($cm^{-3}$) vs. Altitude (km), October 2, 1975

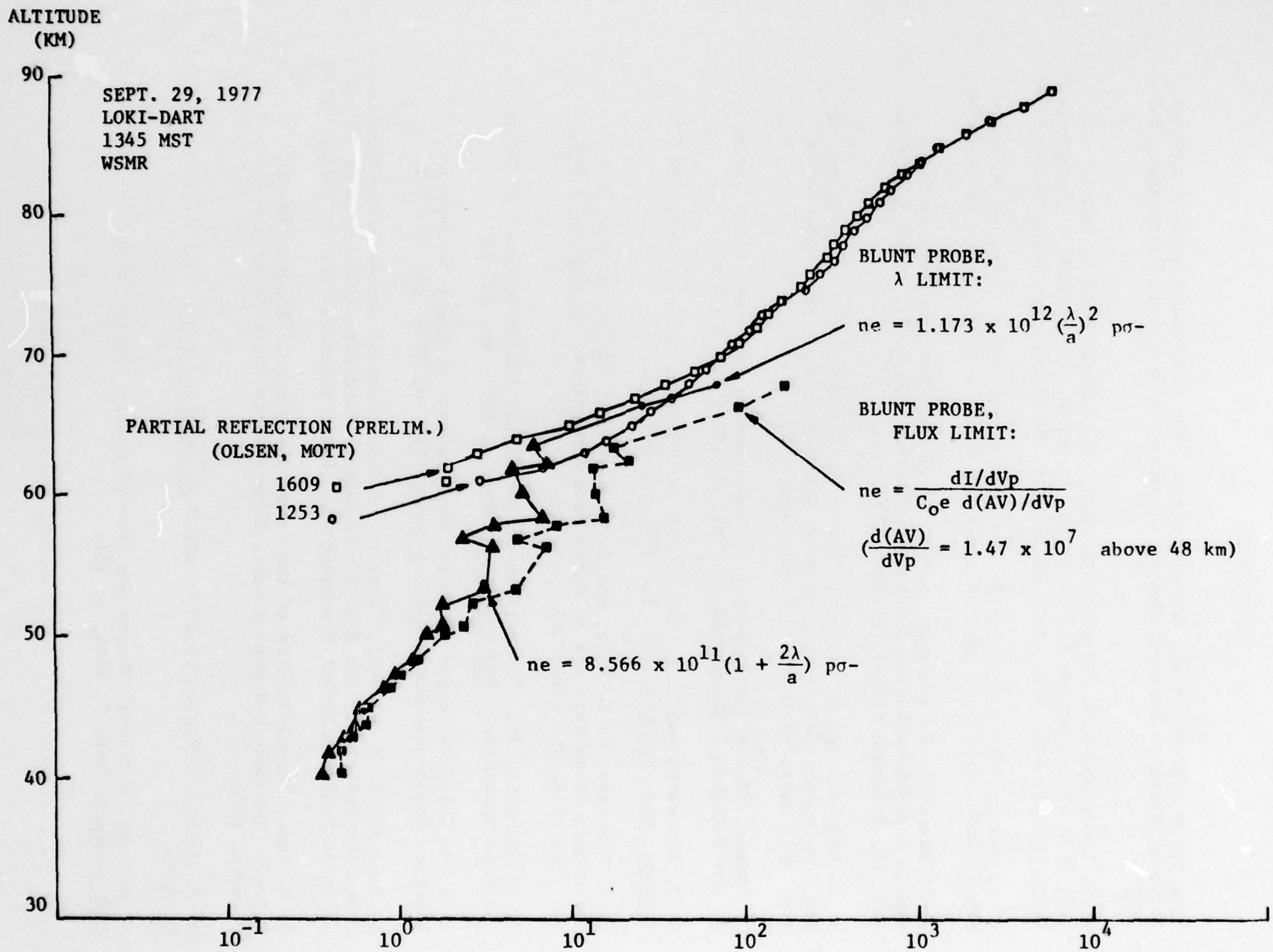


Figure 5. Electron Number Density ($cm^{-3}$) vs. Altitude (km), September 29, 1977

## References


1. "The Upper Atmosphere and Magnetosphere," The Geophysics Study Committee, National Research Council, National Academy of Sciences, Washington, D.C., 1977.

2. D. W. Hoock and M. G. Heaps, "DAIRCHEM: A Computer Code to Model Ionization-Deionization Processes and Chemistry in the Middle Atmosphere," Users Manual, Atm. Sci. Lab., White Sands Missile Range, N.M., March 1978.

3. M. G. Heaps, "The 1979 Solar Eclipse and Validation of D-Region Models," ASL-TR-0002, Atm. Sci. Lab., White Sands Missile Range, N.M., March 1978.

4. J. D. Mitchell, R. S. Sagar, and R. O. Olsen, "Positive Ions in the Middle Atmosphere During Sunrise Conditions," in COSPAR Space Research, Vol. 15, Pergamon Press, New York, 1977.

5. J. D. Mitchell and L. C. Hale, "Electrical Conductivity Measurements in the Stratosphere Using Balloon-Borne Blunt Probes," ASL-CR-78-0263-2, Atm. Sci. Lab., White Sands Missle Range, N.M., June 1978.

6. L. Thomas, "Recent Developments and Outstanding Problems in the Theory of the D-Region," Radio Science, Vol. 9, 1974, pp. 121-136.

7. E. T. Chesworth and L. C. Hale, "Ice Particulates in the Mesosphere," Geophys. Res. Letters, Vol. 1, 1974, pp. 347-350.

8. J. P. Cipriano, L. C. Hale, and J. D. Mitchell, "Relation Among Two Ionosphere Parameters and A3 Radio Wave Absorption," J. Geophys. Res., Vol. 79, 1974, pp. 2260-2265.

9. C. F. Sechrist, Jr., "Comparison of Techniques for Measurement of D-Region Electron Densities," Radio Science, Vol. 9, 1974, pp. 137-149.

10. E. A. Mechtly, "Accuracy of Rocket Measurements of Lower Ionosphere Electron Concentrations," Radio Science, Vol. 9, 1974, pp. 373-378.

11. G. Rose and H. U. Widdell, "Results of Concentration and Mobility Measurements for Positively and Negatively Charged Particles Taken Between 85 and 22 km in Sounding Rocket Measurements," Radio Science, Vol. 7, 1972, pp. 81-87.

12. J. N. Rowe, "Model Studies of the Lower Ionosphere," Report PSU-IRL-SCI-406, Ionosphere Research Lab., Pennsylvania State University, December 1972.

13. D. P. Hoult, "D-Region Probe Theory," J. Geophys. Res., Vol. 70, 1965, p. 3183.

14. S. H. Lam, "A General Theory for Flow of Weakly Ionized Gases," AIAA Journal, Vol. 2, 1964, p. 256.

15. A. A. Sonin, "Theory of Ion Collection by a Supersonic Atmospheric Sounding Rocket," J. Geophys. Res., Vol. 72, 1967, p. 4547.

16. T. Lai, "Electron Collection Theory for a D-Region Subsonic Blunt Electrostatic Probe," M.S. Thesis, Aerospace Engineering Department and Ionosphere Research Lab. Report PSU-IRL-SCI-424, Pennsylvania State University, May 1974.

17. L. C. Hale in Methods of Measurements and Results of Lower Ionosphere Structure, Berlin, Akademie-Verlag, 1974, p. 219.

18. P. M. Chung, L. Talbot, and K. J. Touryan, AIAA Journal, Vol. 12, 1974, p. 133.

19. P. M. Chung, L. Talbot, and K. J. Touryan, AIAA Journal, Vol. 12, 1974, p. 144.

20. P. R. Smy, "The Use of Langmuir Probes in the Study of High Pressure Plasmas," Adv. in Physics, Vol. 25, 1976, p. 517.

21. J. S. Chang and J. G. Laframboise, "Theory of Electrostatic Probes in a Flowing Continue Low-Density Plasma," Note Technique CRPE/30, Centre de Recherches in Physique de Environment, Orelean-La-Source France, September 1976.

22. L. C. Hale, "Particulate Transport Through the Mesosphere and Stratosphere," PSU-IRL-PA-77-4, June 1977 (submitted to Nature).

23. E. A. Mechtly, K. Seino, and L. G. Smith, "Lower Ionosphere Electron Densities Measured During the Solar Eclipse of November 12, 1966," Radio Science, Vol. 4, 1969, pp. 371-375.

24. D. P. Hoult, "Weak Shock Waves in the Ionosphere," J. Geophys. Res., Vol. 69, 1964, pp. 4617-4620.

25. L. C. Hale, L. C. Nickell, B. Kennedy, and T. A. Powell, "Supersonic and Subsonic Measurements of Mesospheric Ionization," Radio Science, Vol. 7, 1972, pp. 89-91.

26. K. F. McKenna, "Hypersonic Low Density Shock Layer Structure on Flat-Faced Cylinders," M.S. Thesis, Aerospace Engineering Department, Pennsylvania State University, September 1970.

27. R. L. Long, Jr. and F. W. Vogenitz, "Monte Carlo Simulation of D-Region Sampling," J. Geophys. Res., Vol. 77, 1972, pp. 6181-6193.

28. T. M. York, C. I. Wu, and T. K. W. Lai, "Electron Collection by Blunt Electrostatic Probes Used in Measurements of the Lower Ionosphere," in preparation.

29. T. W. K. Lai, "Electron Collection Theory for a D-Region Subsonic Blunt Electrostatic Probe," M.S. Thesis, Aerospace Engineering Department, Pennsylvania State University, also Report PSU-IRL-SCI-424, May 1974.

30. T. M. York, R. Brasfield, and L. B. Kaplan, "Laboratory Studies of Particle Collection in Scaled Blunt Probe Flows," in preparation.

31. L. B. Kaplan, "Laboratory Simulation of Rocket-Borne D-Region Blunt Probe Flows," M.S. Thesis, Aerospace Engineering Department, Pennsylvania State University, also Report PSU-IRL-SCI-456, May 1977.

32. E. W. McDaniel, Collision Phenomena in Ionized Gases, John Wiley, New York, 1964.

33. L. C. Hale and C. L. Croskey, "Auroral Effects on Atmospheric Electric Fields," Submitted to Nature, October 1978.

34. R. H. Huddlestone and S. L. Leonard, Plasma Diagnostic Techniques, Academic Press, 1965, pp. 151-162.

35. L. Talbot and Y. S. Chow, "Langmuir Probe Response in the Transition Regime," in Proc. of Sixth Rerefield Gas Dynamics Symposium, Academic Press, 1969.

36. D. I. Pullen, J. Davis and J. K. Harvey, "Monte Carlo Calculation of the Rarefield Transition Flow Past a Bluff Faced Cylinder," in Progress in Aeronautics and Astronautics, Vol. 51, Part 1, Rarefield Gas Dynamics, Pitter, Ed., AIAA, New York, 1977.

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